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Household biogas use in rural China: A study of opportunities and constraints

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ABSTRACT

As a renewable energy, biogas is not only an important part of the development of rural new energy, but also an important aspect of sustainable development in China. The development process and present status of household biogas, specifically the opportunities and constraints of household biogas in rural China, are discussed in this paper. Only about 19% of the biogas potential has been utilized in rural China. There are several opportunities for household biogas development in rural China, including the problem of rural household energy consumption, the availability of biogas fermentation materials, national financial subsidies, legal and international clean development mechanisms. Also, more research needs to be done in straw fermentation and cold fermentation technology. Training should be conducted to raise the level of biogas customers in comprehensive biogas utilization. Measures should be taken to improve the follow-up services and management of biogas plants. The information presented in this paper will be helpful not only to the sustainable development of household biogas in rural China, but also to the development of biogas in similar countries around the world.

Contents

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1. Introduction

The development and utilization of renewable energy resources has becoming an important component of a sustainable global energy strategy [1]. In 2006, about 18% of global final energy consumption came from renewables, with 13% coming from traditional biomass [2]. China has a long history of renewable energies use including biomass, solar, geothermal, ocean and wind energy [1]. These resources represent massive energy potential, which greatly exceeds that of fossil fuel resources [3]. Biogas is distinct from the other renewable energies on two fronts: one, it is a comparatively clean high methane fuel, and two, it is important in the collection of organic waste material from which both fertilizer(s) and water for agriculture uses can be produced [4].

As the strategy applying of building new socialism rural and sustainable agriculture in 21 century, The development of rural household biogas is an important way to promote agricultural structural adjustment, increase rural incomes, enhance the ecology of rural areas, and improve the quality of both rural life and agricultural products [5]. The number of household biogas plants in rural China is the highest in the world [6]. By 2007, there were 26.5 million biogas plants, whose output had reached 10.5 billion m^3 (equivalent to more than 100 million tons of standard coal). Household biogas digesters are found throughout the country, mainly in the Yangtze River Basin. Sichuan Province has the largest number of biogas plants, with 2.94 million running [7].

The rapid development of biogas is closely tied to the country's rich experience in developing biogas, the availability of large amounts of fermentation materials, and the strong support of state funds. However, limiting factors still exist. In this paper, we present research on the development process and present status of household biogas in rural China, concentrating on current opportunities and constrains.

2. Household biogas use in China

2.1. Household biogas development process

The research and use of biogas in China has a long history, and the use of hydraulic digesters has been in use for nearly a 100 years [8]. In the 1880s, the first test to ferment biogas was undertaken in Guangdong. Rectangular hydraulic digesters were invented by Luo GuoRui in 1920 in Taiwan, China. A chronology of biogas development events in China is shown in Table 1.

The large-scale development of household biogas in China began in the 1970s [9]. Fig. 1 shows the number of biogas digesters installed between 1973 and 2005 in China [10]. From 1973 to 1983 development fluctuates dramatically; from 1984 to 1994 an adjustment period follows characterized by slow development; from 1995 to 2000 the pace of development steadily increased annually; and by the 21st century, the construction of household biogas digesters had entered a new, sustained and rapid stage.

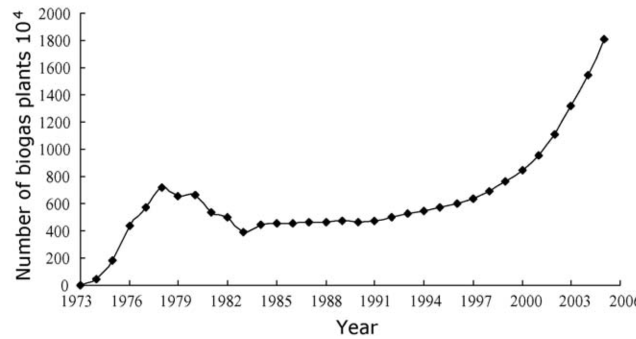

Fig. 1. Number of biogas plants installed in China [modified after 11].

2.2. Household biogas digester design

Luo GuoRui-type biogas digesters were set up in 1920s [8]. This hydraulic biogas digester, constructed of clay, brick, and concrete, was widely used in rural areas in the 1970s [7]. By Chinese national standards, this biogas digester was constructed in 6, 8 and 10 m^3 volumes, and noted in the world for "China's model of biogas digester" [11].

In 2000, commercial household biogas digesters made of glass fiber reinforced plastics (GRP) entered the market [12]. The GRP digester has a thickness of 6–8 mm, a tensile strength of 93.5 MPa, and a bending strength of 109 MPa. The volume range is from 6 to 10 m^3 [13]. A comparison of the key technical indices between the concrete digester and the GRP digester is shown in Table 2 [13]. From Table 2 we can see that GRP digester has a lower coefficient thermal conductivity, a longer operational life, lower maintenance costs, and a shorter construction cycle than the concrete one.

2.3. Household biogas eco-agricultural models

2.3.1. "Three in One" eco-agricultural model

The "Three in One" eco-agricultural model, which combines the biogas digester with a pigpen and toilet, is popular in southern China [14]. The main purpose of this model is simultaneously to solve the rural energy crisis and to improve household hygiene in the rural environment. Biogas can be used as fuel for lighting and cooking, as a fertilizer for growing fruit trees, vegetables and grain, and as a pest control agent [11]. Green food can be developed from the pattern. By connecting the toilet to the biogas plant the spread of disease caused by mosquito breeding can be eliminated. To some extent, it also prevents the occurrence of infectious diseases and the contamination of drinking water by human and animal fecal matter. The "Three in One" eco-agricultural model construction requires less capital input and is quickly effective, which has both strenghtened utility and extended value in the poor economic conditions of the area [14].

Table 1
Chronology of biogas development in China.

Year	Biogas related activity
1880s	The first test to ferment biogas took place in Guangdong
Close of 19th century	The simple biogas digester appeared
1920	Rectangular hydraulic digesters were invented by Luo GuoRui in Taiwan, China
1929	First Chinese institutions to promote biogas established
1931	Biogas was popularized throughout the country for the first time
1933	The training of biogas technology was begun
1958	Biogas was popularized throughout the country for the second time; biogas research institutes established
1970s	Biogas was popularized throughout the country for the third time
2000	The Ministry of Agriculture proposed the "Biologically Enrichment of the Countryside Project"
2003	The Ministry of Agriculture proposed the"Rural Household Biogas State Debt Project"
2007	The Ministry of Agriculture proposed the "Project of Rural Biogas Project"

Table 2
The compare of the key technical indexes between concrete digester and GRP digester.

The style of biogas digester	The thickness of the wall (cm)	Thermal conductivity (kJ/min)	Volume (m^3)	Operation life (a)	Construction cycle (d)	Price (Yuan)	Weight (kg)	Materials	Maintenance
Concrete digester	10	5.44	8	20	10	1800	200 × 40	clay, brick, concrete	2–3a need a small maintenance 4–5a need a big maintenance
GRP digester	8–10	1.42	8	20–30	0.5	1700	200	glass fiber reinforced plastics	No need to maintenance

2.3.2. "Four in One" eco-agricultural model

The "Four in One" eco-agricultural model, which combines the biogas digester, pigpen, solar greenhouse, and toilet, has been proposed for northern China [15]. The greenhouse in this model can be used to increase the temperature of the biogas digester increasing the efficiency of cold weather biogas production. Biogas can be used to increase the temperature of greenhouses. With the temperature of greenhouses increased, vegetables can grow well and pigs are well-fed [16]. Used as a spray for vegetables, the slurry inhibits disease and boosts yields [17]. Because solar greenhouse construction requires a larger input of capital and the growth of greenhouse vegetables more water this model is suitable for regional development in the North where solar energy is abundant, better economic conditions prevail, and water resources are available [18].

2.3.3. "Five in One" eco-agricultural orchard model

The "Five in One" eco-agricultural orchard model, which combines the biogas digester with solar-powered barns, water-saving irrigation system, water cellar, and toilet is proposed for northwest China [19]. Biogas fertilizer is used to grow fruit trees to improve the quality of the fruit [20]. Water resources collected in a water cellar are used in the biogas fermentation, orchard spraying and irrigation. The introduction of water-saving devices, greatly ease the pressure on water resources especially those created by the demands of orchard irrigation making this model is suitable for regional development in the Northwest where severe water shortages exist [21].

3. Opportunities for household biogas use in China

In 2007, 60% of China's population or 0.9 billion people lived in rural area China. The per capita consumption of standard coal is 960 kg, of which 539 kg or 56% is used for daily life, from which straw accounted for 32.8%, fuel wood 21.2%, coal 34.3%, and biogas a mere 1.5% [7]. According to China's rural biogas planning project (2006–2010), by 2010, 0.139 billion rural households are suitable for biogas construction. However, only about 2.65 million households are presently using biogas meaning that only about 19% of the biogas potential of rural China has been achieved [22].

3.1. The problem of rural household energy consumption

Over the long-term, rural household energy consumption in China has mainly depended on traditional biomass energy, such as straw and firewood [23]. At present, straw still accounted for 32.8%, fuel wood accounted for 21.2% and coal accounted for 34.3% of the total consumption [7]. The three energy sources were mainly used for cooking and house heating, which leads to low-energy efficiency and serious environmental degradation. For cooking, the thermal efficiency of straw and firewood is about 20%, and of coal is 30%, but that of straw and firewood is only about 10% if they are burned in traditional stoves [24]. Today, mankind faces two major global climate problems: global warming which is mainly caused by emissions of CO_2, and acid rain, caused by emissions of SO_x as well as NO_x. The direct buring of straw and firewood leads to large emissions of CO and other toxic gases. Coal combustion is not only an important source of CO_2 emissions, but also the main source of increases in SO_2 emissions [25]. Apart from that, coal is also facing the danger of exhaustion. Faced with these problem, we must enhance the efficiency of the conventional energy and increase the proportion of renewable energy sources in the total energy budget.

3.2. Opportunities for renewable energy policy

3.2.1. Financial subsidy

By the 21st century, the Chinese government had begun to focus on supporting rural biogas projects. In 2003, the Central Treasury decided to implement the rural biogas projects. The programs will have invested 61 billion RMB from 2003 to 2010, of which 15 billion RMB is from the National Investment Fund [26]. In 2003, the Ministry of Agriculture Development and Reform Commission started the Project of Rural Household Biogas State Debt and invested 840 million RMB for the construction of household biogas in 22 provinces (autonomous regions and municipalities). In 2004, the movement continued to provide 1 billion RMB of national debt for constructing rural household biogas digesters; in 2005, central investment in the construction of rural biogas funds rose to 2.5 billion Yuan, of which 2 billion was slated for the construction of household biogas digesters and 0.5 billion for the construction of large and medium-sized biogas digesters [9]. As Rural Biogas Construction State Debt Program Management Method stipulates, central finance subsidizes the "one pool and three reforms" in accordance with the following standards: 1200 RMB/household in the northwestern and northeastern areas, 1000 RMB/household in the southwestern area and 800 RMB/household in other areas [27].

3.2.2. Law on renewable energy

On 28 February 2005, PRC Law on Renewable Energy, bringing the exploitation and use of renewable energy to the strategic height of "increasing energy supply, improving energy structure, guaranteeing energy safety, protecting the environmental and realizing the sustainable development of economy and society" [28].

3.2.3. Clean development mechanism

To tackle the problem of global warming, the clean development mechanism (CDM) was put forward in Kyoto Protocol. The clean development mechanism (CDM) is an arrangement under the Kyoto Protocol allowing industrialised countries with a greenhouse gas reduction commitment (called Annex B countries) to invest in projects that reduce emissions in developing countries as an alternative to more expensive emission reductions in their own countries. As a consequence, the development of CDM biogas technology projects and the sale of verified carbon emission

reductions (CER) has opened up new channels of finance for medium-sized biogas project in China, including household biogas digesters in rural areas, leading to an increase projects rate of economic return.

3.3. Biogas fermentation material availability

Livestock and poultry manure, most of which is from cattle, pigs and chicken, and agricultural residues are the main resource for biogas fermentation in rural China. The potential quantity of manure can be estimated by the number of livestock and poultry and the annual dry excrement production of one livestock or poultry [29]. Calculated according to current livestock and poultry production, the total physical quantity of dry excrement resources in China is 1467 million tons, of which 1023 million tons can be collected, equivalent to 107 million tons of standard coal [30]. According to the plan for livestock industry development, livestock and poultry manure in 2010 and 2020 will reach 2.5 billion tons and 4 billion tons, respectively, from which the collected amount is equivalent to 120 and 160 million tons of standard coal, again, respectively [31].

The quantity of agricultural residues available as a resource is mainly due to the output of crops, the collection of coefficients and consumption purposes [32]. The main approaches to straw utilization in China are papermaking, forage, rural energy resource, and recycling in field and collection (including some losses), accounting for 2.1%, 28%, 53.6% and 16.2%, respectively [33]. According to current crop production, there are about 681 million tons of agricultural residue produced annually in China, of which 546 million tons can be collected. Apart from other uses, about 290 million tons can be used as an energy resource, equivalent to 145 million tons of standard coal. Judged over the long-term, the total amount of straw will continue to maintain growth with population growth [30]. After 2030, 400–500 million tons can be used as a modern high-efficiency energy resource, equivalent to 200–300 million tons of standard coal.

4. Constraints on household biogas use in China

4.1. Straw fermentation technology

Cellulose, hemi-cellulose, lignin, pectin and wax are the main organic component of straw, which is lacking in effective nitrogen and phosphorus components, hindering microbial fermentation [8]. In the process of straw anaerobic methane fermentation, the anaerobic microbe has a weak degradation of digestion ability for lignocelluloses, leading to a slow hydrolytic process and a low degree of hydrolysis, which affects the subsequent acidification and gasification process. As a result, the anaerobic digestion of crop residues is inefficient and time-demanding, produces less gas and results in poor efficiency of input–output, which keeps crop stalks from being used in large-scale biogas production [34]. Many researchers have achieved some success on the pretreatment of straw by physical, chemical and biological methods to increase the utilization of straw [35]. However, many problems still exist. First, the pretreatment increases the cost; second, the chemical pretreatment of straw causes secondary pollution. Moreover, the biological pretreatment of straw is still in the experimental stage presenting difficulties for large-scale applications. Therefore, finding a suitable method for pretreating straw is the focus of future research.

4.2. Cold fermentation technology

In rural China, the fermentation temperature of household biogas is at normal temperatures, generally between 8 and 25 °C. The minimum temperature for biogas production is 10 °C, with the rate of production increasing with increased temperature [36]. Winter (November to March) conditions in northern China are unsuitable for biogas production because the daily mean temperature is lower than 10 °C. As a result, the time available for the digester to produce biogas efficiently and rapidly are 8–9 months [37]. Therefore, more research needs to be done to increase the efficiency of biogas production in colder regions.

4.3. Low comprehensive biogas utilization

The technique of comprehensive biogas utilization reduces costs and improves economic benefits, ameliorates rural ecosystems, raises rural incomes, and contributes to sustainable development [38].

The majority of biogas users have not received technically training. As a result, they are unable to combine biogas technology with eco-agriculture technology. Instead, biogas is used only for lighting and cooking. Biogas fermentation products have a low level of use in China, the potential rate of economic exploitation is less than 1%, and the rate of ecological exploitation is only 4% [39]. In 2005, there were 6.73 million rural households using multi-purpose technology for biogas, accounting for 37.3% of total rural household users [7]. So, training should be conducted to raise the level of comprehensive biogas utilization.

4.4. Poor follow-up services and management of biogas digesters

The follow-up services and management of biogas digesters, is a key question of rural energy construction and development. The development of household biogas in rural China focuses mainly on construction and fails to consider management. Thus, a number of biogas projects have broken dawn due to a lack of follow-up services and management. This national phenomenon is attested to by the 2007 statistic: of the 26.5 million biogas digesters in China's rural areas, only 60% of which were operating normally [12]. Biogas technology literate staff are in short supply. Most provinces have only small county-level rural energy offices whose employees number between three and seven. Staffs are unable to adapt to the rapid developments taking place in the field of rural household biogas digester technology. This also seriously affects the efficiency of biogas construction and sustainable development [40]. Biogas lights, stoves and other equipment are all professional equipment, which is difficult to buy in the market; even when available, farmers are unable to correctly install them [37]. So measures to improve household biogas digester follow-up and management services need to be taken.

5. Conclusions

The development process and present status of household biogas, specifically the opportunities and constraints of household biogas in rural China, are discussed in this paper. There are several opportunities for household biogas development in rural China, including shortage of rural energy, the availability of biogas fermentation materials, national financial subsidies, legal and international clean development mechanisms. Constraints encountered in developing household biogas in rural China include straw and cold fermentation technology, low comprehensive biogas utilization, poor follow-up services and management of biogas digesters. Also, more research needs to be done in straw fermentation and cold fermentation technology. Training should be conducted to raise the level of biogas customers in biogas comprehensive utilization. Measures should be take to improve the follow-up services and management of biogas plants.

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References

[1] Chang JYC, Leung D, Wu CZ, Yuan ZH. A review of the energy production, consumption, and prospect of renewable energy in China. Renew Sust Energ Rev 2003;7:453–68.
[2] Global Status Report 2007.
[3] Wrixon GT. Renewable Energy—2000. Berlin: Springer-Verlag Press; 1993.
[4] Taleghani G, Kia AS. Technical-economic analysis of the Saveh biogas power plant. Renew Energ 2005;30:441–6.
[5] Zhou DJ. Counter-measures for dealing with the development of biagas in rural areas under the new situation. Mod Agric Sci Technol 2006;5:103 [in Chinese].
[6] Deng GL, Li KL, Li X, Zhang B. Role of biogas technology in new socialistic countryside. Trans CSAE 2006;22(Suppl. 1):61–4 [in Chinese].
[7] Hu QG. Problem and recommendation of biogas development in rural China. Agric Eng Technol 2008;5:15–8 [in Chinese].
[8] Zhang GQ. Technology and application of biogas. Beijing: Chemical Industry Press; 2005 [in Chinese].
[9] Gao YC, Kuang ZS, Pan MS, Huang XG, Chen W, Ye MQ, et al. Development progress and current situation analysis of the rural household biogas in China. Guangdong Agric Sci 2006;11:22–6 [in Chinese].
[10] Ministry of Agriculture. China agricultural statistics report of 1973–2005. Beijing: China Agriculture Press; 1973–2005 [in Chinese].
[11] Zeng XY, Ma YT, Ma LR. Utilization of straw in biomass energy in China. Renew Sust Energ Rev 2007;11:976–87.
[12] Zhang WD, Yin F, Liu N, Liu SQ, Gong HL, Li JC, et al. Industrial development and marketable analysis on rural biogas. Trans CSAE 2006;22(Suppl. 1):72–6 [in Chinese].
[13] Li DS. Production and application of household biogas digester made of glass fiber reinforced plastics. Liaoning J Agric Vocat Tech Coll 2008;1:36–7 [in Chinese].
[14] Wang YM, Liu RH, Bian ZM. Economic evaluation on trinity biogas ecosystem. Renew Energ 2005;116(2):39–42 [in Chinese].
[15] Wang CX, Li XD, Gao JK, Gao F. Four-in-one eco-agricultural model and its application. Chin J Eco-Agric 1998;1:77–9 [in Chinese].
[16] Zhang WD, Su HC, Liu JC, Wu XK. Comprehensive utilization of human and animal wastes. In: Proceedings of the first international conference on ecological sanitation; 2001.
[17] Dang CY, Zhang YD. Application of the "Four-in-One" eco-agricultural models. Renew Energ 2004;115(3):4–53 [in Chinese].
[18] Chen Y, Yang GH, Feng YZ, Ren GX. Evaluations and empirical studies on the regional suitability of "Four-in-One" eco-agricultural models. J Northwest A & F Univ (Nat Sci Ed) 2008;36(9):45–50 [in Chinese].
[19] Qiu L, Yang GH, Yang SQ. A study on the designs of the optimal ecological orchard project model in the Loess Plateau. J Northwest A & F Univ (Nat Sci Ed) 2001;29(5):65–9 [in Chinese].
[20] Li JJ, Yuan XQ, Ma L, Li N, Xie QH. The effect of biogas manures on fruite tree cultivation. J Henan For Sci Technol 2009;29(1):61–2 [in Chinese].
[21] Liu JJ, Qiu L, Yuan JW. Benefit evaluation of economy on loess altiplano biogas eco-orchard model. J Agric Mech Res 2007;4:49–52 [in Chinese].
[22] Ministry of Agriculture. China's rural biogas project planning (2006–2010). Beijing: Science and Technology Education Department of Ministry of Agriculture; 2007 [in Chinese].
[23] John B, Bo S, William W. The economics of sustainable energy for rural development: a study of renewable energy in rural China. Energ Policy 1998; 26(1):45–54.
[24] Wang SR, Wang ZY, Qiu QR. High efficient energy saving shelf pre-installed kang-linked stove. Renew Energ 2006;126:75–7.
[25] Zhou ZR, Wu WL, Chen Q, Chen SF. Study on sustainable development of rural household energy in northern China. Renew Sust Energ Rev 2008;12:2227–39.
[26] Qi ZH. Construction of circle economy and eco-town. China Popul Resour Environ 2003;13(5):111–4 [in Chinese].
[27] State Commission of Development and Reform. Rural biogas construction and debt project management methods [in Chinese].
[28] PRC law of renewable energy [in Chinese].
[29] Yuan ZH, Wu CZ, Ma LL. Biomass energy utilization principles and technologies. Beijing: Chemical Industry Press; 2005 [in Chinese].
[30] Wang ZY, Li JF. China renewable energy industry development report 2007. Beijing: Chemical Industry Press; 2007 [in Chinese].
[31] Ministry of Agriculture. Livestock industry development planning (2010–2020). Beijing: Science and Technology Education Department of Ministry of Agriculture; 2007 [in Chinese].
[32] Gu S, Zhang X, Wang G. Energy utilization and agricultural sustainable development. Beijing: Beijing Press; 2001 [in Chinese].
[33] Wang XH, Feng ZM. Biofuel use and its emission of noxious gases in rural China. Renew Sust Energ Rev 2004;8:183–92.
[34] Wu SJ, Liu SY, Wang XD, Liu XE, Wang S. Summary and prospect of dry fermentation technology for straw biogas production. China Biogas 2008; 26(4):20–3 [in Chinese].
[35] Chen XH, Zhu HG. Research progress and prospects for producing biogas from crop straws. Trans CSAE 2007;23(3):279–83 [in Chinese].
[36] Ma HR. Main technical points for household methane pool gas production. Renew Energ 2003;108:29–30 [in Chinese].
[37] Hu HY. Analysis of the development of biogas digester in rural China—a case study in Yiyuan County. Shandong Sust Dev 2007;2:19–22 [in Chinese].
[38] Bian YS. Waste disposal and recycling in ecological agriculture. Beijing: Chemical Industry Press; 2001 [in Chinese].
[39] Zhang PD, Yang YL, Li XR. Present situation and potentiality of biogas comprehensive utilization in China. China Biogas 2007;25(5):32–7 [in Chinese].
[40] Sheng K, Zhang YL. On sustainable development in rural marsh gas construction in China. J Huazhong Agric Univ (Soc Sci Ed) 2007;4:50–2 [in Chinese].

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